

# Orbit response matrix measurements and model calibration for the Fermilab Booster

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# Model calibration using optimization (penalty) function:

$$F = \sum_{i,j} \left[ \left( \frac{\partial x_i}{\partial \theta_j} \right)_m - \left( \frac{\partial x_i}{\partial \theta_j} \right)_t \right]^2 \frac{1}{\sigma_{ij}^2}$$

Measured response

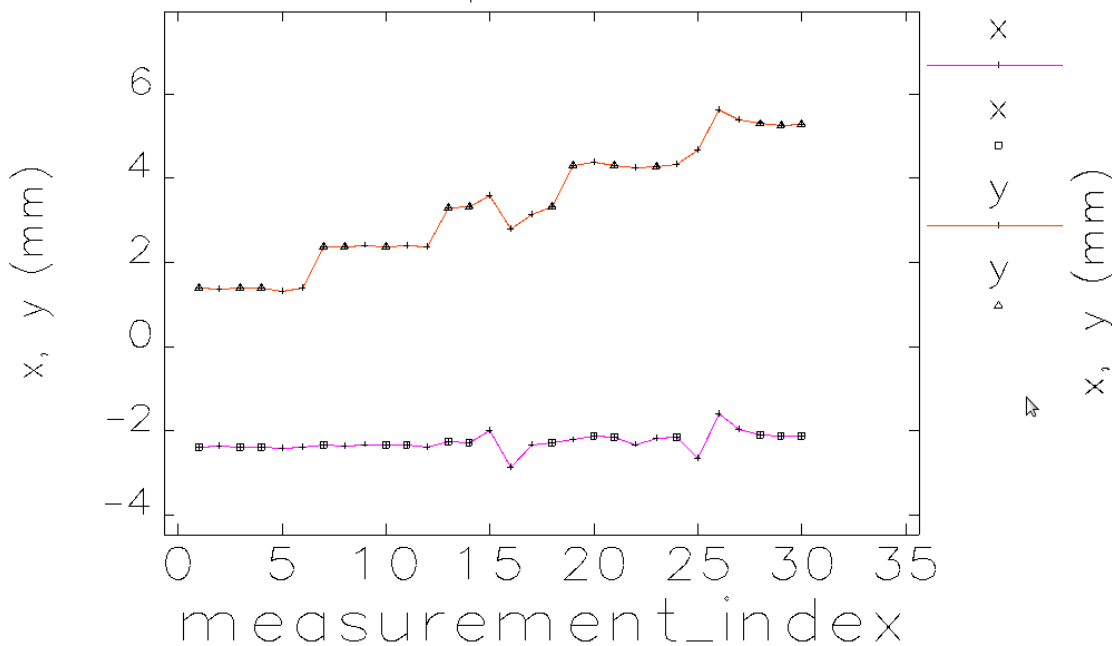
Model

Measurement accuracy

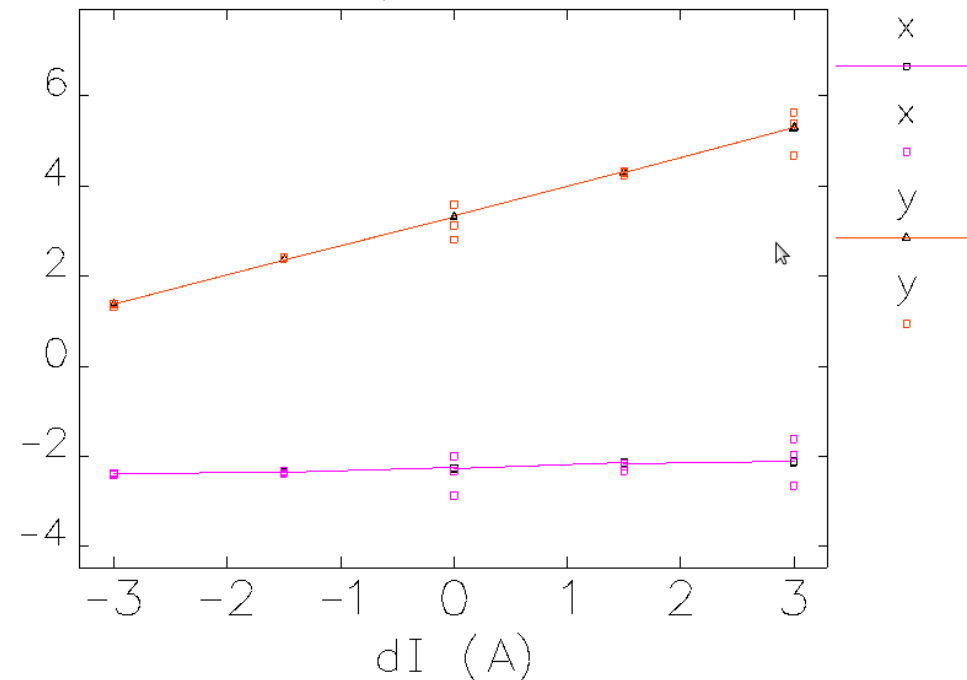
The objective is to find a set of hidden model parameters (focusing errors, BPM calibrations etc.) which minimizes  $F$ . SVD-based optimization is typically used.

## Booster orbit response measurements:

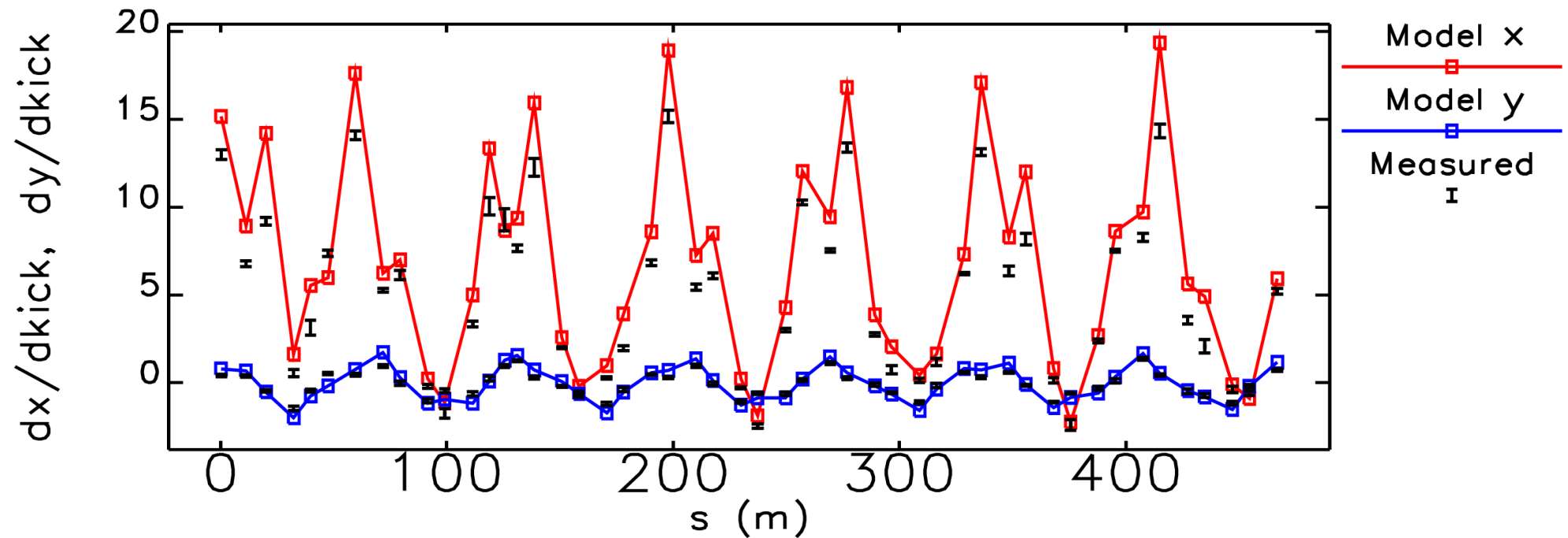
20L response to VL5



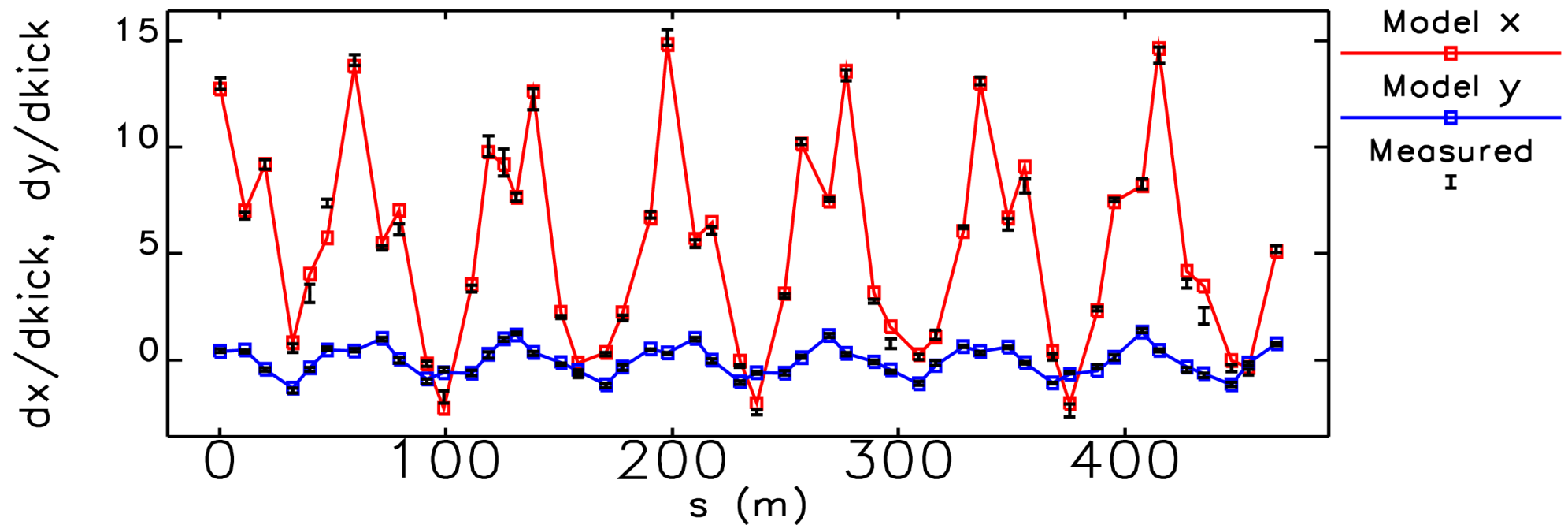
20L response to VL5



## Before model calibration:



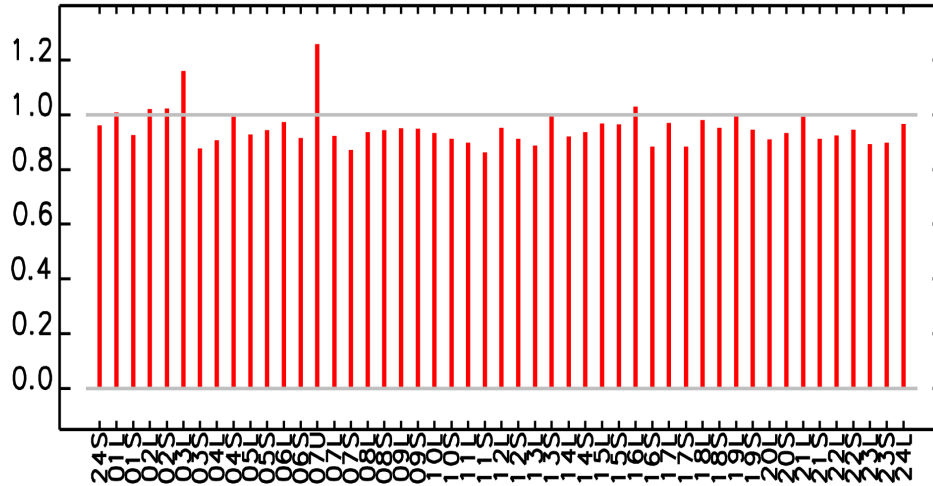
## After model calibration:



# Resulting BPM and corrector calibrations:

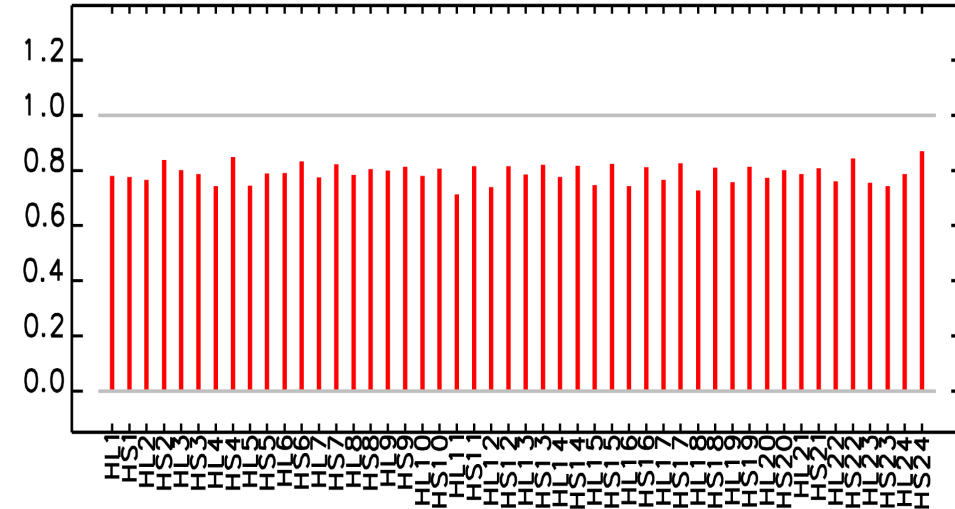
X\_GAIN

X-plane BPM calibrations:



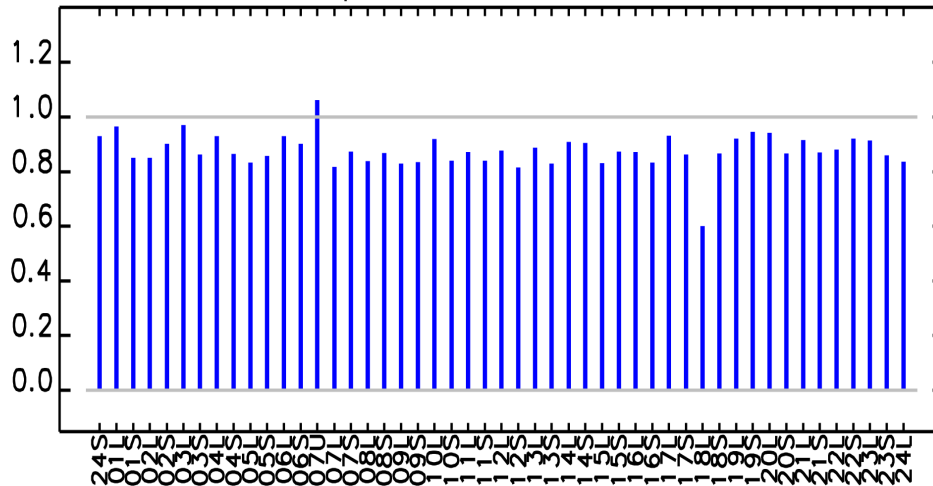
corrector\_calibration

Horizontal dipole corrector calibrations:



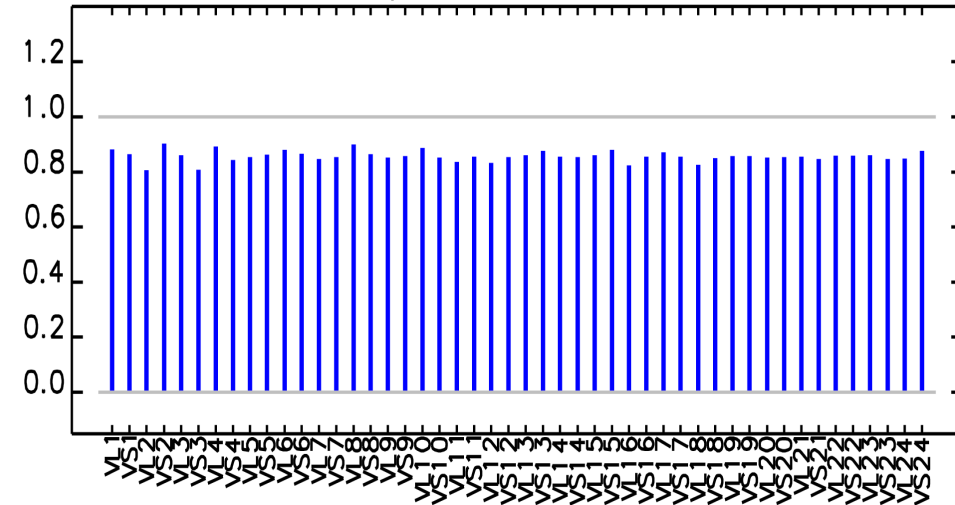
Y\_GAIN

Y-plane BPM calibrations:



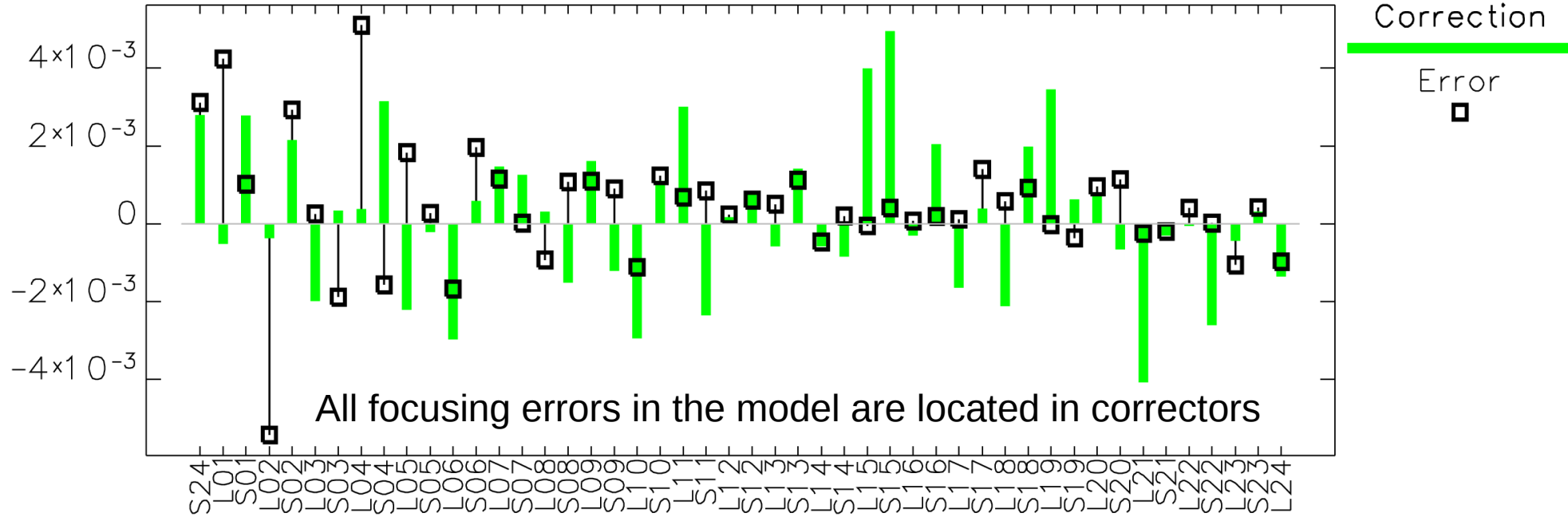
corrector\_calibration

Vertical dipole corrector calibrations:

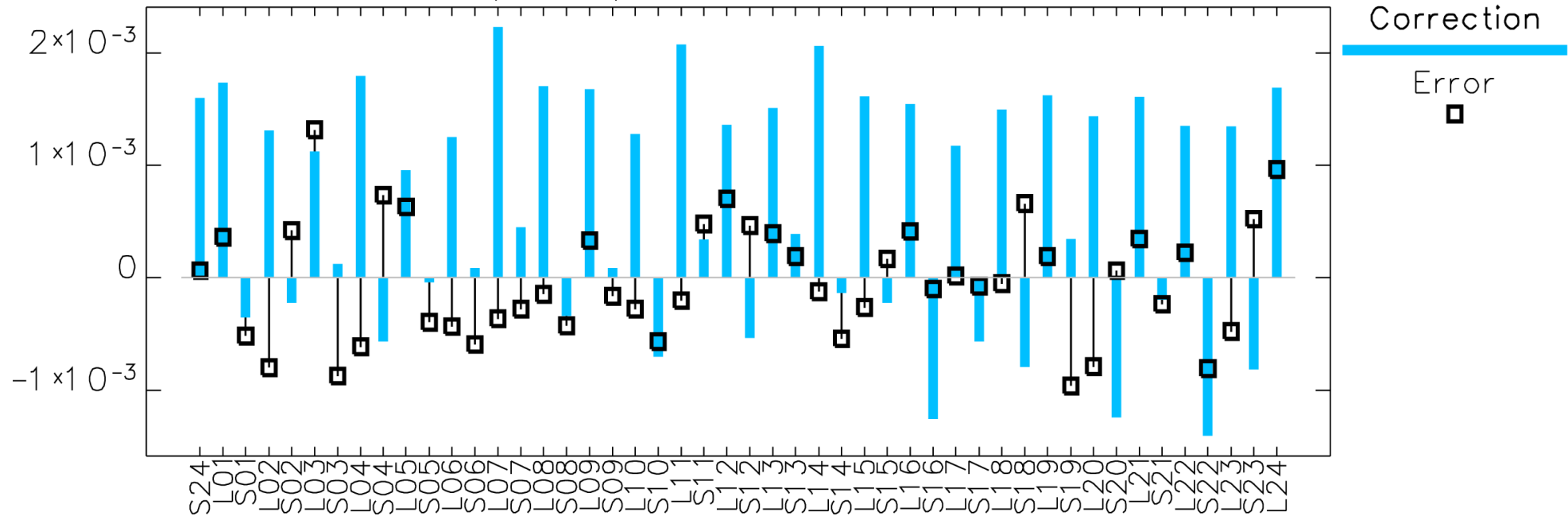


# Resulting focusing errors:

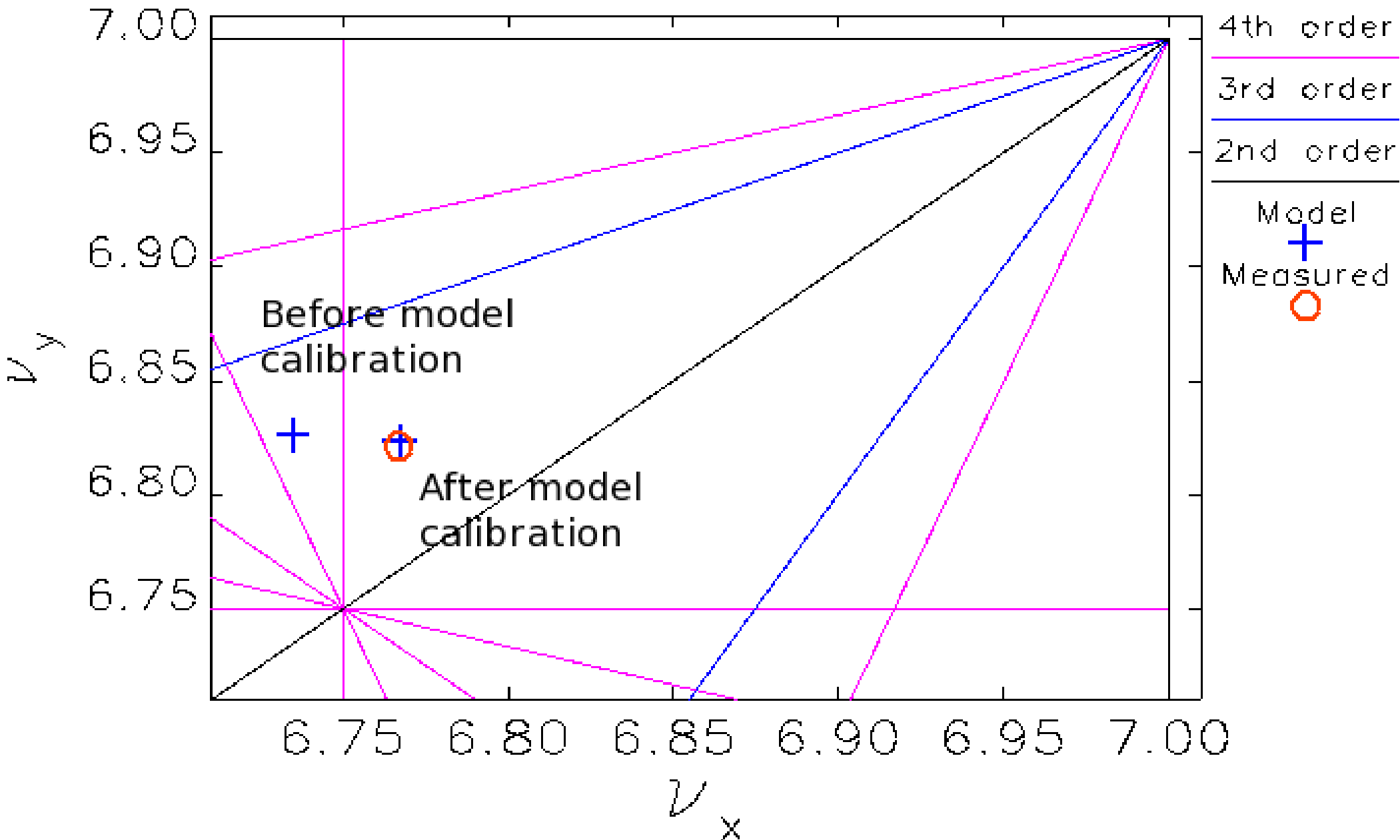
Quadrupole correction & errors:



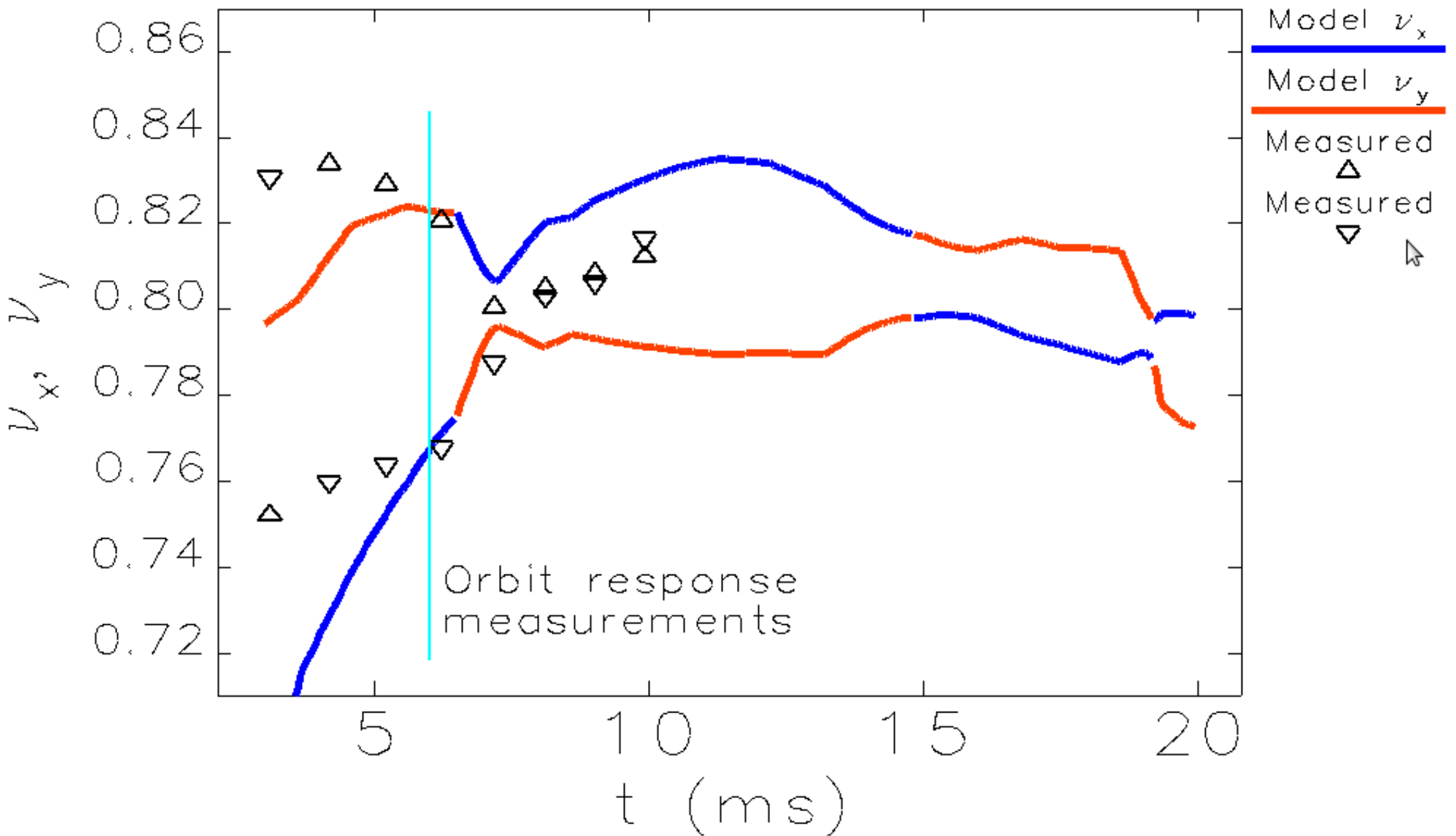
Skew quadrupole correction & errors:



Betatron tunes:  
(measured tunes were not used in model calibration)



Betatron tunes vs time:  
(assuming that focusing errors do not change with time)

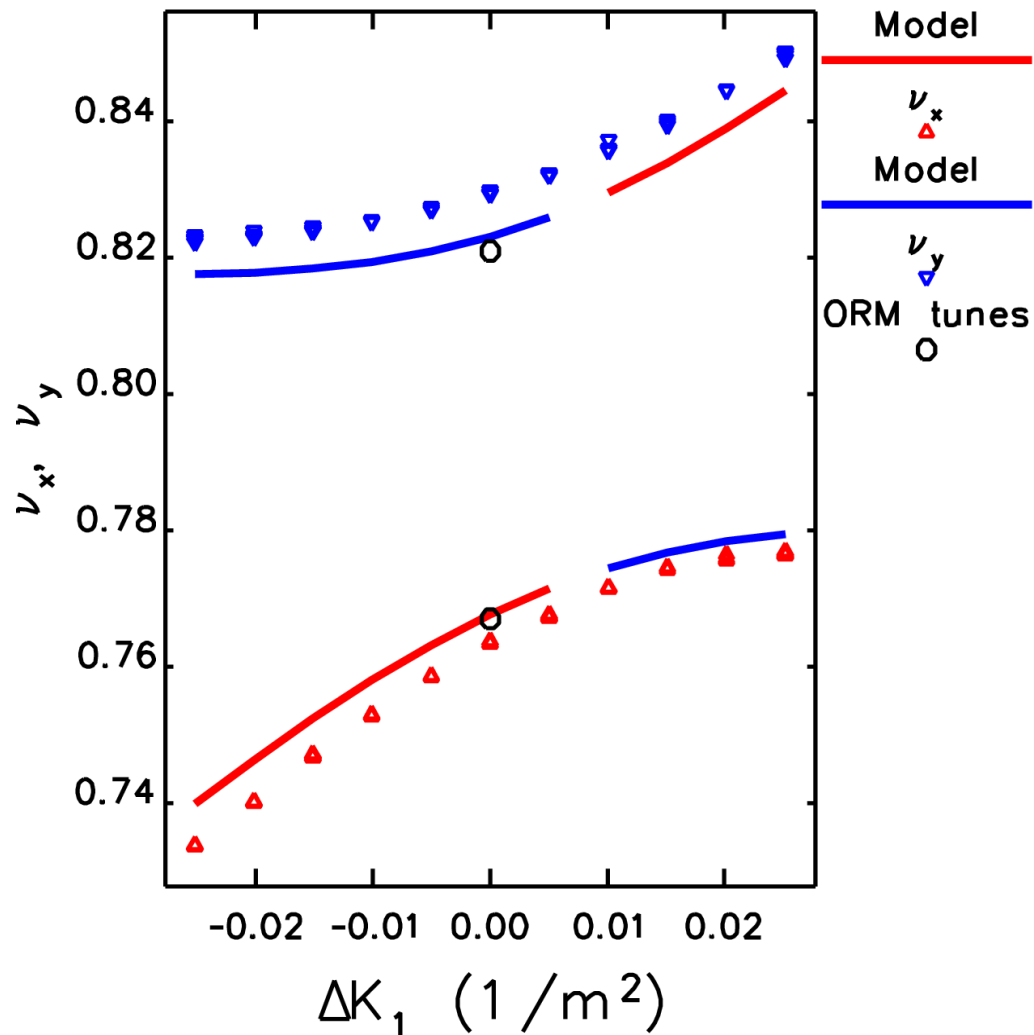


=> Focusing errors do change with time!

# Betatron coupling: (measured tunes were not used in model calibration)

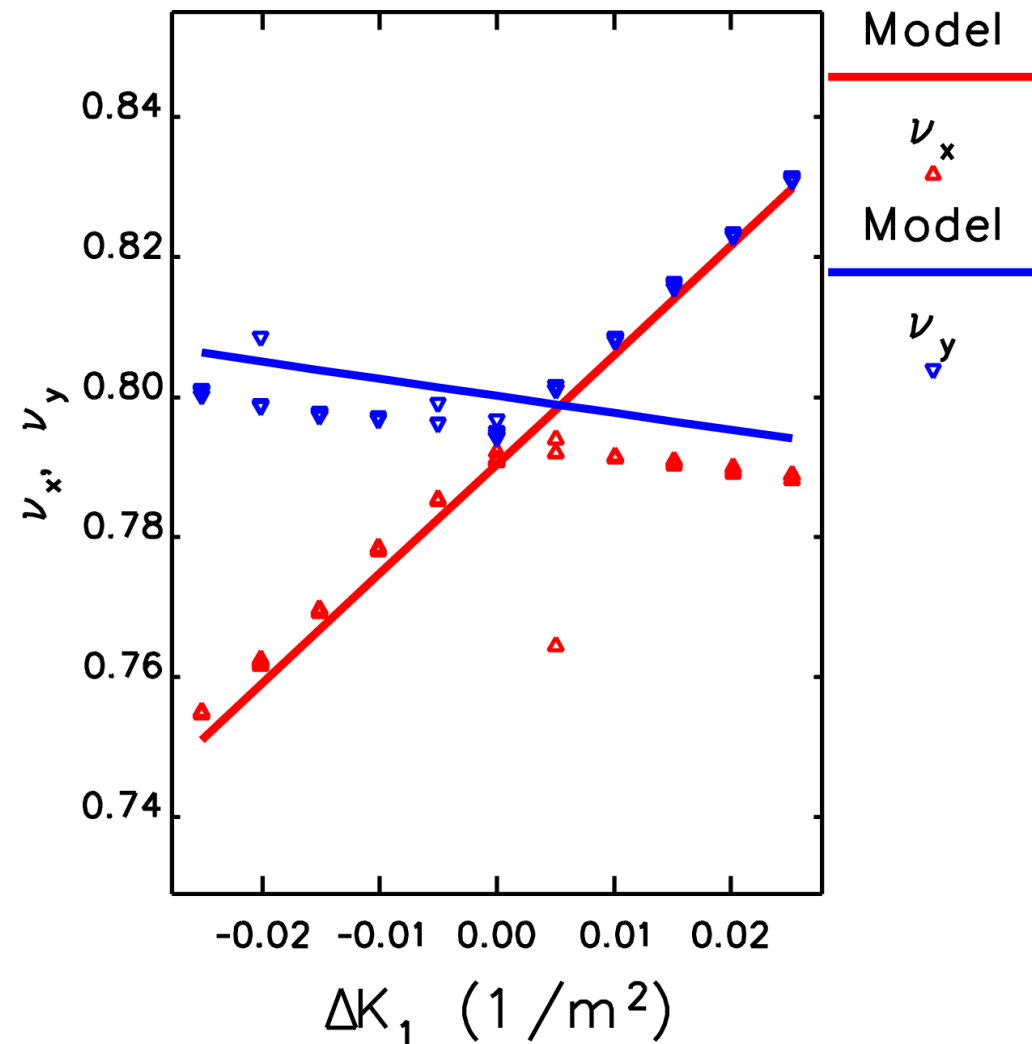
## Before correction:

Tune response to all S-quads



## After correction:

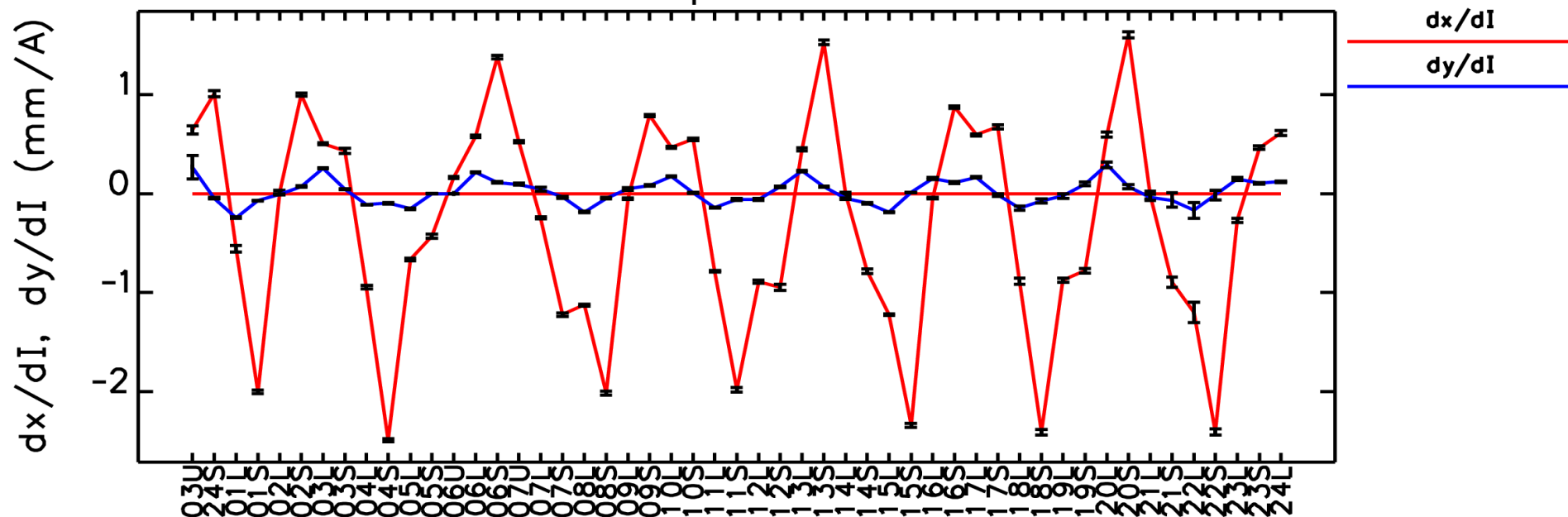
Tune response to all S-quads





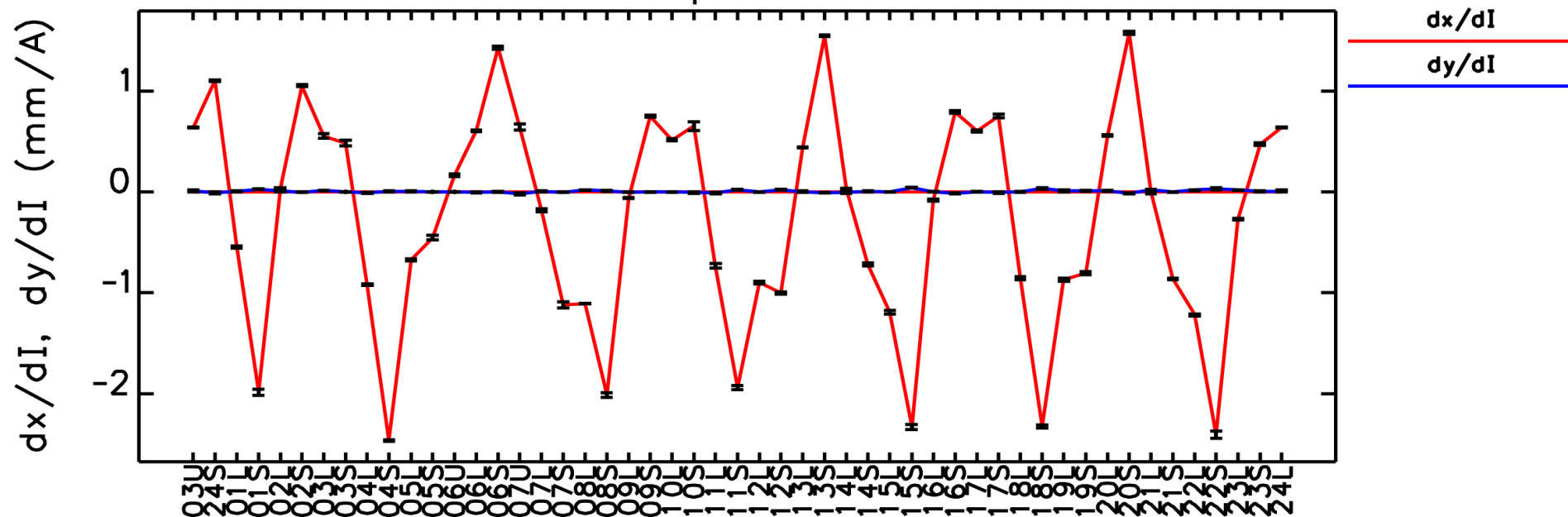
# Before coupling correction:

Orbit response to HS1



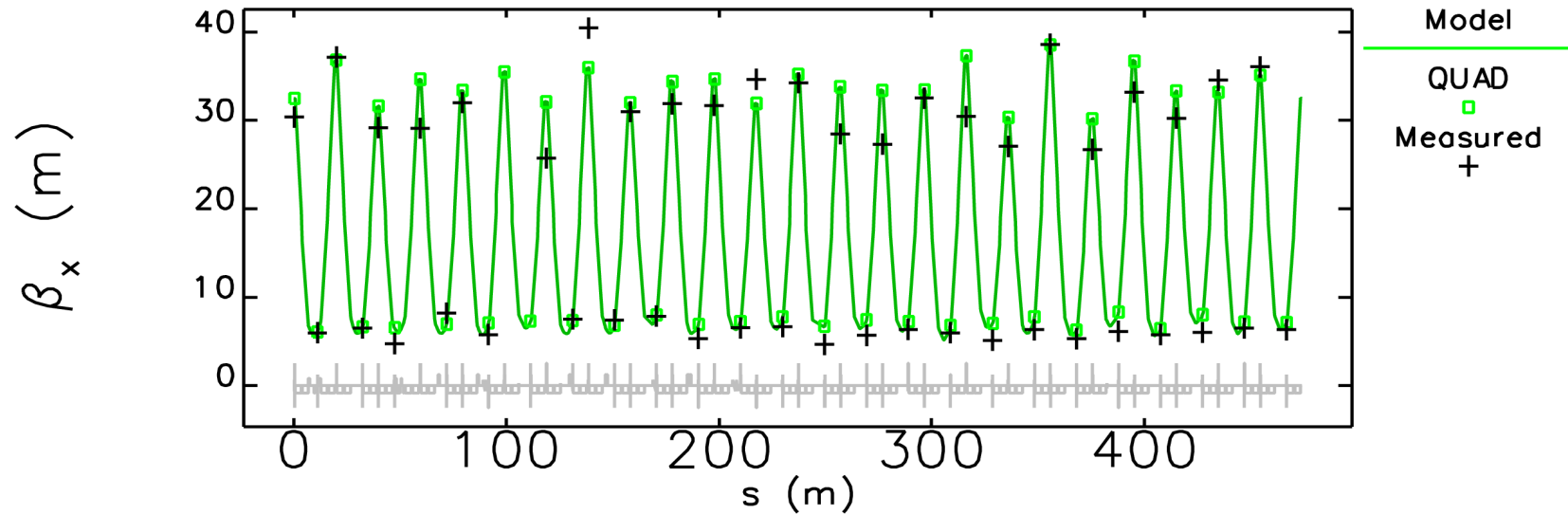
# After coupling correction:

Orbit response to HS1

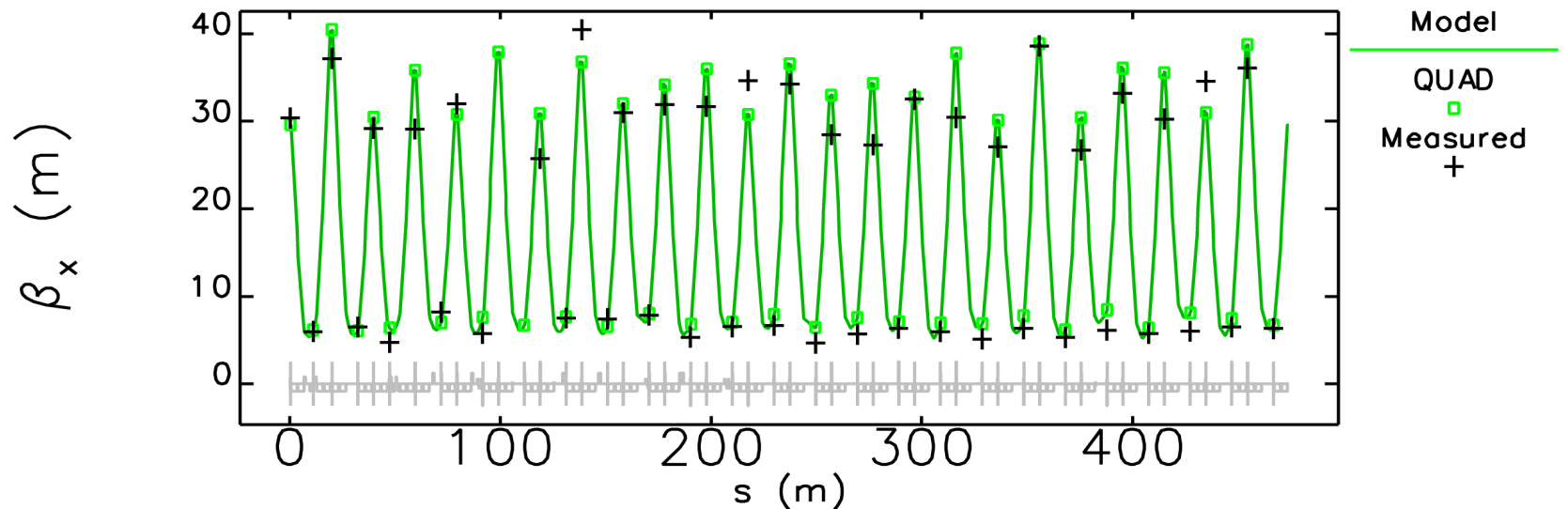


# Beta-function from quadrupole scans: (coupling is corrected and tunes are separated)

## Design model:



## Calibrated model:



The difference is probably due to quadrupole calibration errors

# Conclusions:

- Booster optics is very well reproducible from pulse to pulse => accurate orbit and tune response measurements are possible
- Precise Booster model was obtained for  $t=6$  ms using orbit response matrix (LOCO) technique
- The obtained model was successfully used to correct coupling in the Booster
- In order to understand the nature of focusing and calibration errors orbit response matrix (and if possible tune responses) should be measured during whole ramp